

Abstract

Phase-correlation is a popular motion estimation algorithm known to recover translation of an object from a pair of its images taken before and after the displacement. Based on Fourier phase shift theorem, it estimates the translation from normalized cross power spectrum of the two images. Though originally developed for recovering translation between successive video frames[1], recently several new applications of phase correlation were discovered including medical image registration[2], vibration analysis[3], and particle image velocimetry[4]. However, its application for analysis of diffraction fringes was unknown hitherto.

This thesis presents for the first time, phase-correlation based analysis of diffraction fringes generated by micron sized objects. A hitherto unexploited feature of diffraction pattern is identified and used for measurement of displacement between specific orders of diffraction fringes through phase-correlation. Based on this measurement, two problems in optical metrology are addressed through a new route. First problem, measurement of micro-dimension wire diameter and slit width is addressed by phase-correlation based displacement measurement between equal order fringes. Second problem, simultaneous measurement of refractive index and thickness of transparent plates is addressed by monitoring displacement suffered by suitable fringe orders using phase-correlation.

Recently, there is a growing interest in developing extensions of phase-correlation partly due to its inherent immunity to correlated noise & computational simplicity and partly because of its suitability in several applications. In recent past, two different extensions of phase-correlation, one, based on singular value decomposition and another, based on Gaussian filtering were reported independently and demonstrated to achieve $\frac{1}{100}$ of a pixel accuracy in recovering translation from two images in incoherent light. In this thesis, the two extensions are combined for the first time, and high subpixel accuracy is demonstrated for diffraction fringe analysis.

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ing mirror symmetric intensity distribution and are separated by a characteristic distance. An accuracy better than $\frac{1}{200}$ of a pixel is achieved for estimating separation between such fringes.

Non-contact measurement of thin wire diameter lying in the range of 5 to 500 microns with an accuracy better than 0.5 % of dimension is a complex problem owing to its dependence on several parameters. Such measurement in industrial and research environments is traditionally carried out by illuminating a wire with a laser to generate an interference pattern due to diffraction. Diameter is then estimated by measuring fringe spacing, the separation between successive minimas in the interference pattern. In spite of simplicity of the approach and developments of several techniques for estimation of fringe spacing, the measurements are not to the satisfaction of several researchers due to influence from many parameters like lens blurring, CCD noise, speckle noise, vibration, light polarization etc. In this thesis, a new approach based on analysis of diffraction fringes by phase-correlation is presented. The proposed approach is based on treating the diffraction pattern as a collection of translated replicas in the form of equal order fringes. Measurement of wire diameter is carried out by estimating separation between equal order fringes. An accuracy better than 0.5% of dimensions is achieved for wires and slits lying in the range of 200 to 450 microns.

Simultaneous measurement of refractive index and thickness of transparent plates provides crucial information for many applications including glass & polymer manufacturing, semiconductor & optoelectronic industries and has been attempted by several researchers in last few decades. Due to two unknowns, the measurement calls for utilization of either two different phenomena in a single apparatus or single phenomenon followed by two records by varying suitable parameter. Several methods utilizing one or two phenomena and two records based on interferometry, confocal microscopy, measurement of reflectance and transmittance, ellipsometry etc were reported. However, simultaneous measurement based on a single phenomenon and single record was hitherto not reported. In this thesis, a novel methodology for simultaneous measurement of refractive index and thickness of transparent plates using single phenomenon and single record is proposed and demonstrated. The proposed technique relies on phase-correlation based measurement of lateral shifts suffered by diffraction fringes when they are simultaneously transmitted through a transparent plate at two different angles. A pair of chosen fringes of an diffraction pattern generated using a diffraction grating are transmitted through a plate at two angles. Measurements on plates of fused quartz and borosilicate crown glass have shown an accuracy of 0.022 & 0.09 in refractive index and 122 & 155 microns in thickness respectively.